Uncovering Akaroa's Eruptive History: Reconstructing a flank scoria cone in Le Bons Bay, Banks Peninsula

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Abstract
Exposed pyroclastic units along the coast of Le Bons Bay on Banks Peninsula, Canterbury, NZ have been analysed, using physical data and photographs taken in the field, to investigate the eruption of parasitic monogenetic cones related to the Akaroa Volcano (9-8 MYA). These deposits, which are the result of lateral injection of basaltic magma, have been subdivided into six lithofacies based on clast concentration, size, shape and degree of welding. The physical properties of the facies, as well as the geomorphic features of the coastal deposits at Le Bons can be correlated to typical scoria cone morphologies and used to locate the eruptive vent and determine the pre-erosional cone extent as well as determine the eruptive phases of the eroded cone. The deposits reveal a basaltic scoria cone approximately 820 metres in diameter with an eruptive vent that reached as high as 65 metres which went through different phases of eruption ranging from phreatomagmatic during formation to strombolian and hawaiian during cone building.

Introduction

Banks Peninsula is located southeast of Christchurch on the South Island of New Zealand (Figure 1). It formed primarily from the activity of three volcanoes. Lyttleton Volcano (11.0 – 9.7 Ma) to the northwest, and Akaroa Volcano (9.3-8 Ma) to the south east, were the main volcanic centres with Mt Herbert volcanics occurring contemporaneously in the central region (Hampton and Cole, 2009). The Akaroa Volcanic group constitutes a majority of the landmass of Banks Peninsula. Most of the central and south eastern peninsula is formed from lava flows radiating from around Akaroa Harbour. Akaroa also has a series of flank scoria cones, formed from lateral injection of magma along planes of weakness in the crust and overtopping volcanic deposits. Some of the oldest stratigraphic indicators of the volcano can be found in the various bays near sea level, where younger lava flows have eroded to expose glimpses of Akaroa's explosive past.

Flank scoria cones can be used to understand the eruptive history of extinct volcanic systems as they reflect the previous surface morphology (Hampton and Cole, 2009). Scoria cones, which are fed by dikes that radiate from either the central magma chamber or a shallower reservoir, can also provide information about the inner plumbing of a volcano (Acocella and Neri, 2002). It is also possible to reconstruct the conditions under which a volcano was active, as the feeder dikes often form chains of scoria cones parallel to the maximum horizontal compressional stress (Corazzato et al, 2006).

A typical scoria cone contains several zones that have diagnostic eruptive faces. These zones consist of the lower and mid crater, upper crater, outer and inner wall and flanks (Vesperman and Schmincke, 2012). The crater facies transition from densely welded spatter in the lower crater to non-welded rounded bombs in a lapilli matrix in the upper crater. Upper crater deposits are often thickly blanketed with well sorted lapilli which can stretch to great distances from the cone complex. Outer wall facies are usually characterized by brecciated basal fine ash containing lapilli sometimes overlain with poorly sorted coarse brecciated lithics torn up from the initial eruption. Inner wall facies generally transition from beds of coarse scoria bombs and lapilli proximal to vent to less welded finer grained deposits distally. On average, the outer flanks of scoria cones are comprised of well sorted air fall lapilli deposits often in conjunction with talus slopes (Trent, 2012).

Studies have been done specifically dealing with scoria cones and scoria deposits relating to the Akaroa Volcanic Group. Cones have been documented at localities including Little Okains, Pigeon Bay, Onawe Peninsula, Robinsons Bay, Hammond Point, Childrens Bay, Wainui Bay and Anchorage Bay (Johnston et al, 1997; Trent, 2012). Different facies in these cones suggest a varied eruptive history including phases of phreatomagmatic activity (seen in brecciated basaltic lapilli tuff), Hawaiian-type fire fountaining (seen in welded spatter deposits) and Strombolian type eruptions (seen in non-flattened scoria deposits). In Little Okains a geochemical analysis of deposits revealed that the scoria is benmorite and therefore more evolved than the overtopping lava flows (hawaiite). It was suggested this was due to the parasitic cone being fed by a smaller, shallower chamber than the large regional lava flows (Shirley, 2012). Pigeon Bay scoria deposits were of hawaiite composition and heavily modified by erosion before being buried by larger flows which suggests that the scoria cone was part of an earlier eruptive sequence in Akaroa's history.

Le Bons Bay is located 11 kilometres to the northeast of Akaroa Harbour. The eastern side of the bay contains several low elevation scoria deposits overlain by large regional lava flows that stem from the Akaroa eruptive centre. This study focuses on a series of deposits located at and above the sea platform approximately 300 metres from the headlands. The deposits are approximately 500 metres across and are found up to 65 metres above sea level. Through understanding the eruptive facies, cycle and morphology of these features as well as the geochemistry of the scoria and surrounding deposits, we can enhance the current understanding of Akaroa's history.

Methods

Field based mapping and sample collection were the primary source of data. Fieldwork was conducted on foot and focused on scoria deposit textures and placement from 7 different areas along a section of sea platform 300 metres from the headland of Le Bons Bay. Photographs were taken and correlated with the deposit descriptions to locate the major facies along the platform and delineate large deposit boundaries across sections. These photos were analysed to determine the eruptive history by studying the colour, texture, and clast size of distinct deposits as well as looking at clast roundness to determine eruption type and relative distance of deposition from the eruptive centre. Units were divided into different facies using clast concentration and size, degree of roundness, degree of welding, and percent ash. In areas where no field data was collected weathering patterns were used to determine the type of deposit and correlation to other known deposits.

Hand samples were studied in thin section to ascertain vesicle content and crystal texture. Geochemical data was acquired through x-ray fluorescence to compare the chemical make-up to other cones around Akaroa.

Scoria Facies and Deposits

Field mapping and photo analysis reveal several different types of scoria deposits. The pyroclastic deposits contain a range of clasts, from ash to bombs. The clasts range from low to moderately vesicular. Analysis done on scoria clasts revealed a basaltic composition with well formed euhedral olivine crystals in a groundmass predominantly composed of unaligned needle feldspar and pyroxene with some amorphous glass. Overtopping lavas have a basaltic trachy-andesitic composition. Bomb morphologies are largely irregular, with some flattened from spatter impact, but also include cowpat, and spindle shapes.

The table below defines the six lithofacies and their locations in the field area which can be correlated to Figure 2. Figure 3 provides textural examples for reference.

Facies	Description	Locations (in Figure 2)
Ash-rich deposits	Red brown ash with coarse to medium lapilli in undulatory lenses and beds and occasional bombs	Site 6
Bomb-rich deposits	Clast supported non-flattened bombs and lapilli – some red brown ash present Bombs up to 50 cm in length and welding is present	Shore platform of Sites 1 & 2
Mixed scoria deposits	Yellow to red brown ash matrix with flattened and non-flattened lapilli and bombs with varying concentrations of clasts (>20% flattened bombs)	Sites 1, 2, 4, 5, 6
Densely welded scoria deposits	Welded black and brown flattened cowpat bombs which show spatter patterns	Sites 2 & 3
Agglutinated lava	Welded scoria grading in and out to agglutinate lava bed	Site 2
Ash beds	Red Orange ash layer approximately 10 cm thick In sharp contact with bed above – often gradational with bed below	Sites 1, 2, & 5

The sea platform on the southern extent of the cone, seen in figure 4, is comprised of bomb-rich deposits of indeterminate thickness due to its continuation below sea level. This bomb rich deposit is overlain by a 10 cm thick ash bed that pinches out toward the north and is in sharp contact with several mixed scoria deposits (Sites 1 & 2). The first of these deposits is yellow in colour and approximately 1 m thick and is overlain by red-brown ash and brown bombs and lapilli that continue upward for more than 10 metres. These deposits are continuous for approximately 200 metres along the platform. Moving north the bomb-rich deposits and ash bed become topped with agglutinated lava before they dip below sea level and the platform becomes primarily mixed scoria that grades laterally into ash rich deposits (fig 5). The north-eastern extent of scoria (Sites 6 & 7) is ash rich and mixed scoria deposits and creates a baked margin with the overtopping lavas. The scoria dips at a steeper angle than the overlying lava. Above the sea platform the deposits range from densely welded scoria deposits, approximately 3 to 5 metres thick, farther inland near Site 3 to less welded mixed scoria closer to sea which reach down to the sea platform towards Sites 6 and 7.

Discussion

The scoria facies suggest that there is a succession from inner cone to distal facies present in the field area. Depositional environments can be broken into crater, flank, and apron using the facies relationships as defined by Figure 6. Ash rich deposits and ash beds would be distal to the eruptive crater found in the outer wall or flank. Mixed scoria would be found closer to vent in the inner wall. Bomb rich deposits would be located more proximal to vent in the crater as would the densely welded scoria deposits. Before erosion occurred the vent was located near site 3 while the lesser degree of welding and higher ash content at sites 1, 2, 4, 5, 6, and 7 suggests the location of the flank and apron.

Textures of deposits suggest some variation in the eruptive style of the cone through its lifetime. The bomb-rich deposits along the southern extent give a glimpse at earlier phases of cone building that may suggest a more "wet" phreatomagmatic eruption as the bomb concentrations are high but the bombs themselves are not flattened as they would be in a hawiian style eruption. The larger quantity of matrix supported lapilli rich deposits found higher up in the stratigraphic record would suggest a more explosive strombolian eruption. The few areas with more agglutinated and welded deposits, both closer to the shore platform and at higher elevations, would suggest more hawaiian style eruptions. Therefore the cone went through different periods of phreatomagmatic, hawaiian, and strombolian eruptions.

Though weathered at the sea platform, the cone is well preserved in the upper regions as the younger lava flows from Akaroa built around and over the northern flank. The resulting amphitheatre shape nicely outlines the cone boundaries and could be used as a diagnostic feature for future flank cone exploration on the peninsula. Evidence of an erosional contact between scoria and overtopping lava flows suggests that there was a substantial period of time between scoria eruption and regional lava deposition. This could also account for the difference in chemical composition between the basaltic trachy-andesitic lava flows and the basaltic scoria. The lava flows represent a later period of maturation of the main Akaroa magma chamber while the more primitive basalt of the scoria signifies an earlier stage of magmatism. Erosion could also explain the relatively high angle between the proposed flank and crater which is unusual for most scoria cones. The cone itself may have been much larger in diameter than the current morphology suggests.

Conclusion and Farther Research

Scoria deposits present near the headlands of Le Bons Bay exhibit physical characteristics of proximal, medial and distal facies and locate the eruptive vent around Sample Site 3. The deposit types represent different periods of eruption ranging from "wet" phreatomagmatic to "dry" hawaiian to strombolian. The erosive shape of the cone, largely preserved by the overtopping lava flows, may be used in aerial reconnaissance to locate more cones on the peninsula. Farther research would involve relating the eruption packets and facies to other scoria deposits in Le Bons Bay, including deposits yet to be studied to see if there is an eruptive correlation between them.

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Appendix

Figure 1

Figure 2.

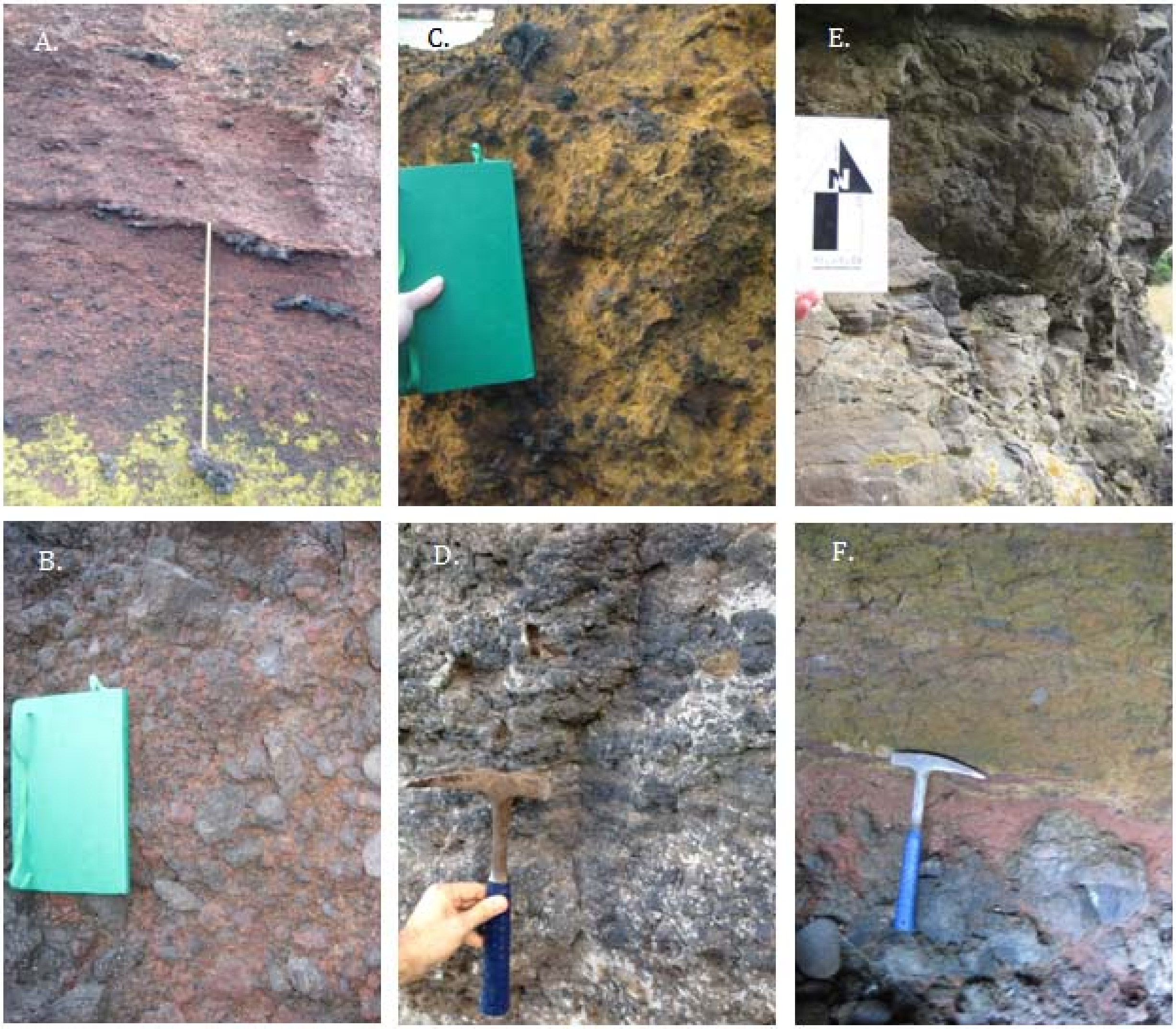

Figure 3.

Figure 4.

Figure 5.

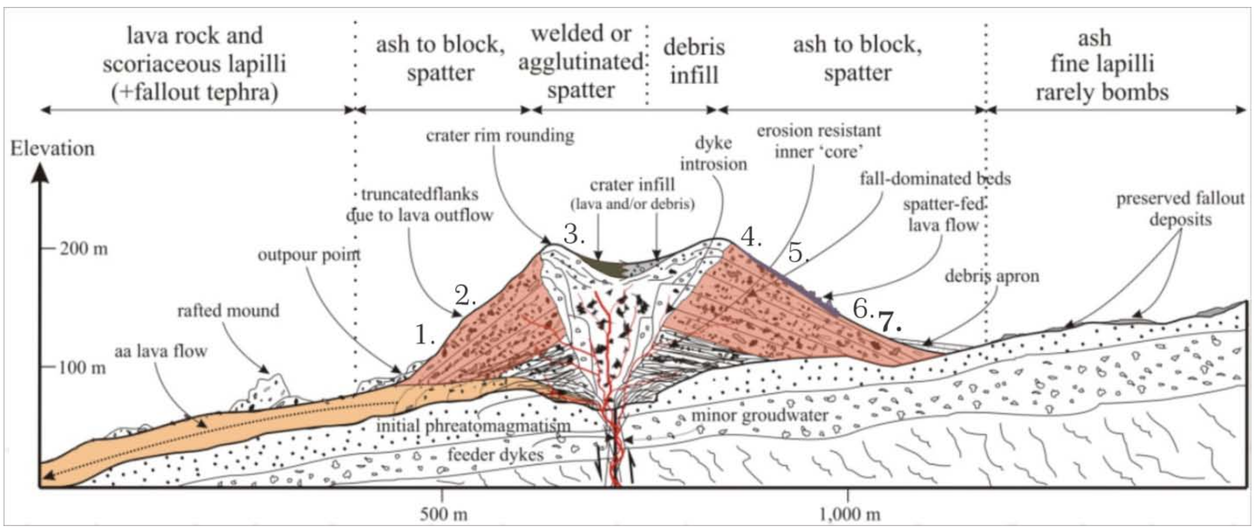

Figure 6.

Captions

Figure 1. Location of Banks Peninsula along New Zealand's southeastern coast (above left). Le Bons Bay is highlighted on the eastern flank of the peninsula. Above right shows Le Bons in detail, highlighting the field site and location of the involved scoria deposits.

Figure 2. Extent of mapping area in Le Bons Bay with deposits and projected extent of cone located on map. Red and Blue dots show locations of Figures 3 and 4 respectively.

Figure 3. Typical examples of Le Bons Bay lithofacies discussed in Table 1. A, Ash-Rich Deposits grading into Mixed scoria (site 6). B, Bomb-Rich Deposits (site 2). C, Mixed Scoria Deposits (site 1). D, Densely Welded Scoria Deposits (site 3). E, Agglutinate Lava (site 2). F, Ash bed overtop of bomb rich deposit and in sharp contact with overlying mixed scoria deposit

Figure 4. View of deposits on the southwest flank of cone showing locations of sites 1 through 3 and relationships of deposits.

Figure 5. View of deposits on the northeast flank of cone showing locations of sites 3 through 7 and relationships of deposits.

Figure 6. Schematic cross-section through a typical scoria cone depicting typical deposits and giving approximate locations of each field site around the cone. Figure adapted from Kereszturi and Nemeth (2012).